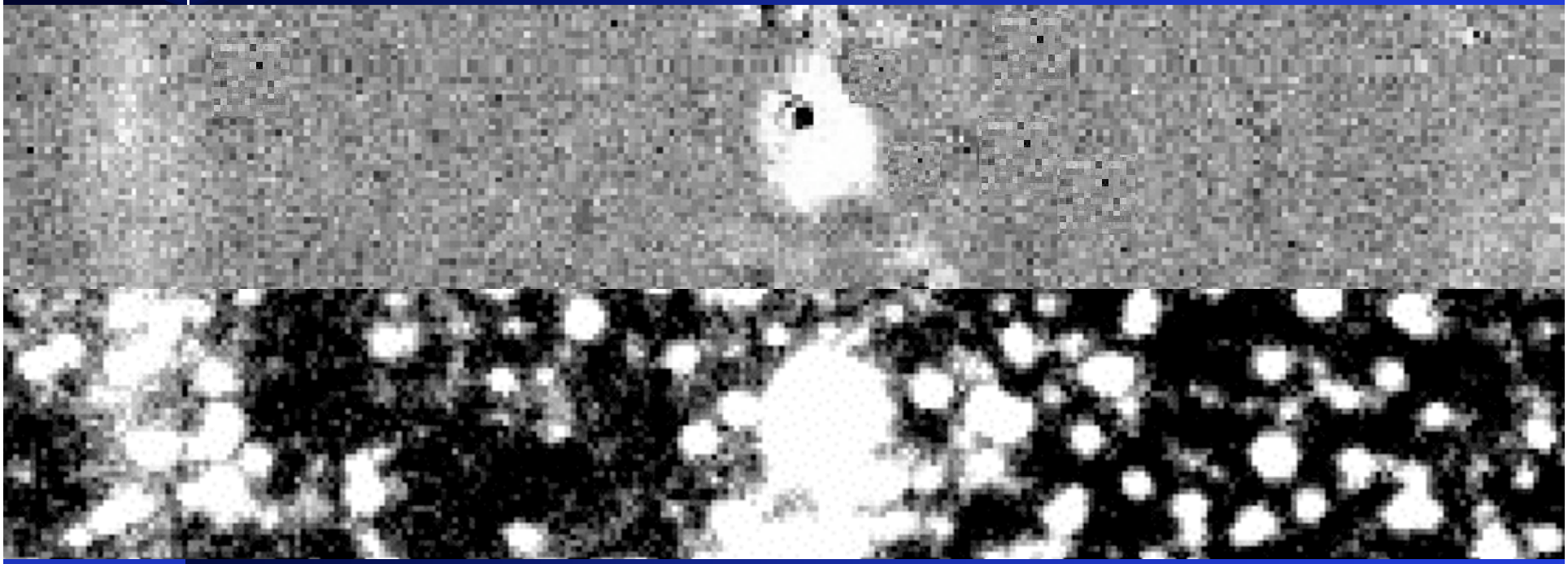
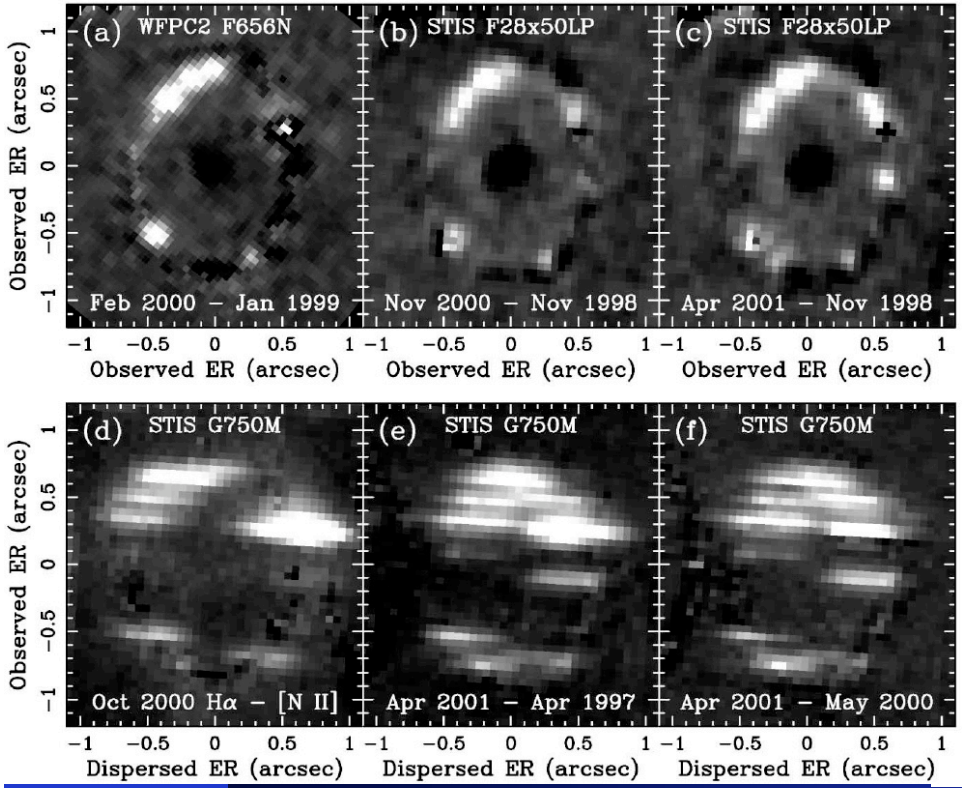
Light Echoes From SN 1987A

(And a quick status report on spectroscopy of SNR 1987A)

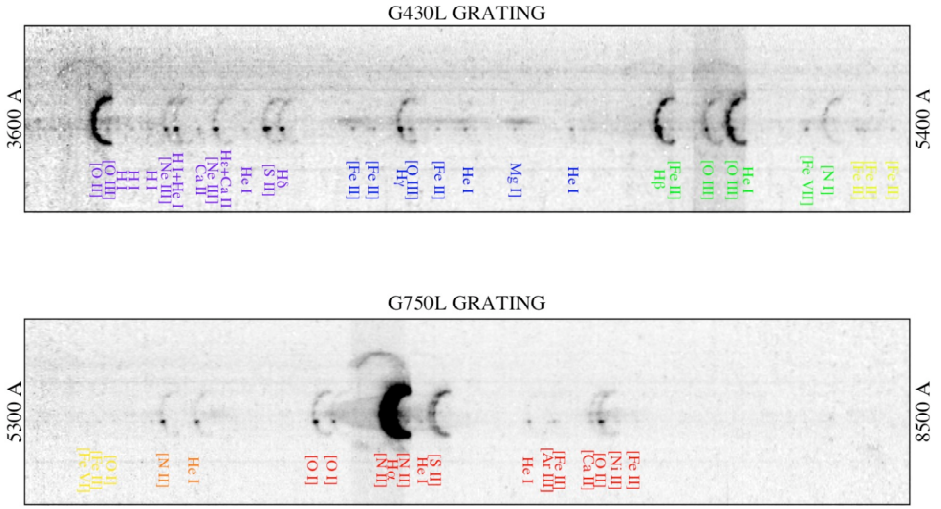


- Imaging of SN 1987A since 1988 at CTIO, LCO
- High-res. imaging since 1989; HST since 1994 (2000)
- Low/High-res. 2-D spectra since 1989 at CTIO (since 2006 at Magellan)
- Co-investigators Kunkel, Sugerman, Heathcote, Lawrence, SAINTS

STIS Optical Longslit Spectra



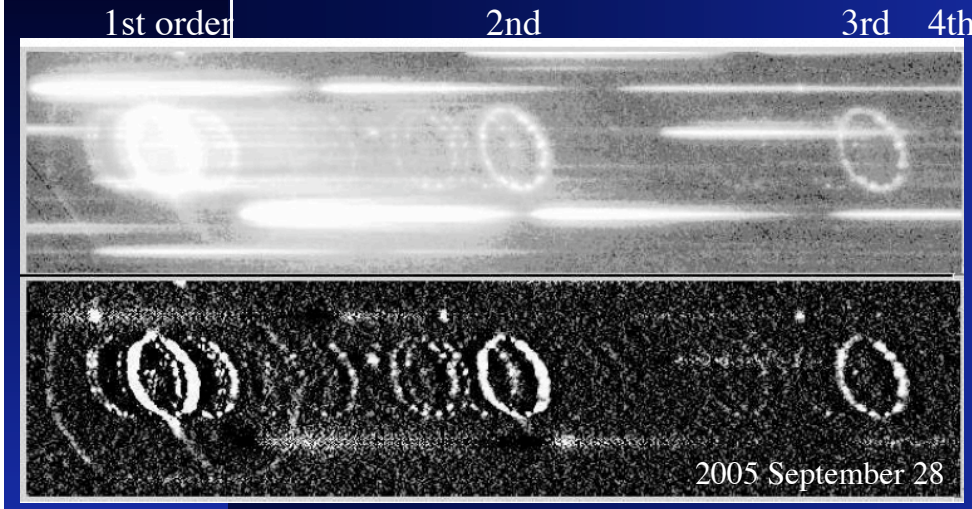
SNR 1987A: NORTHERN HALF OF INNER RING



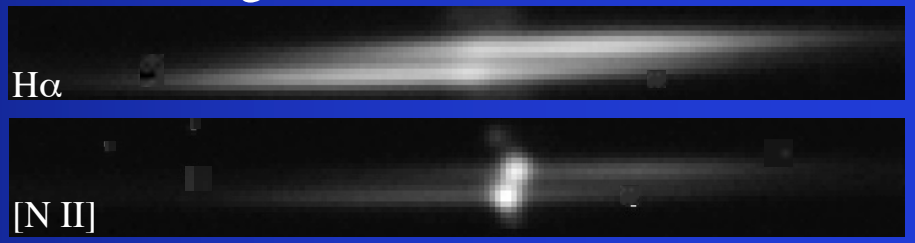
HST/STIS-G750M

HST/STIS-G430L+G750L

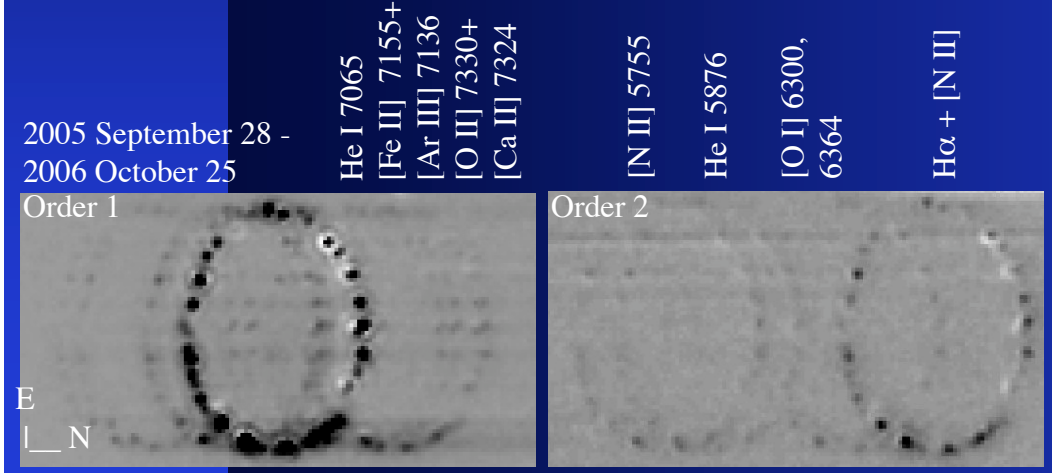
ACS-Grism & Ground-based Spectra



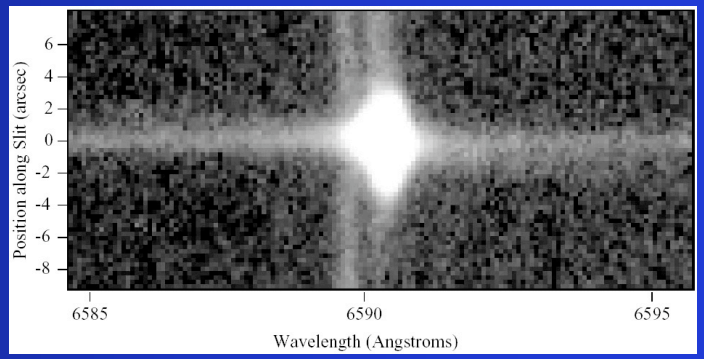
Magellan/MIKE after 2005



3200-10000A, 10 km/s resolution



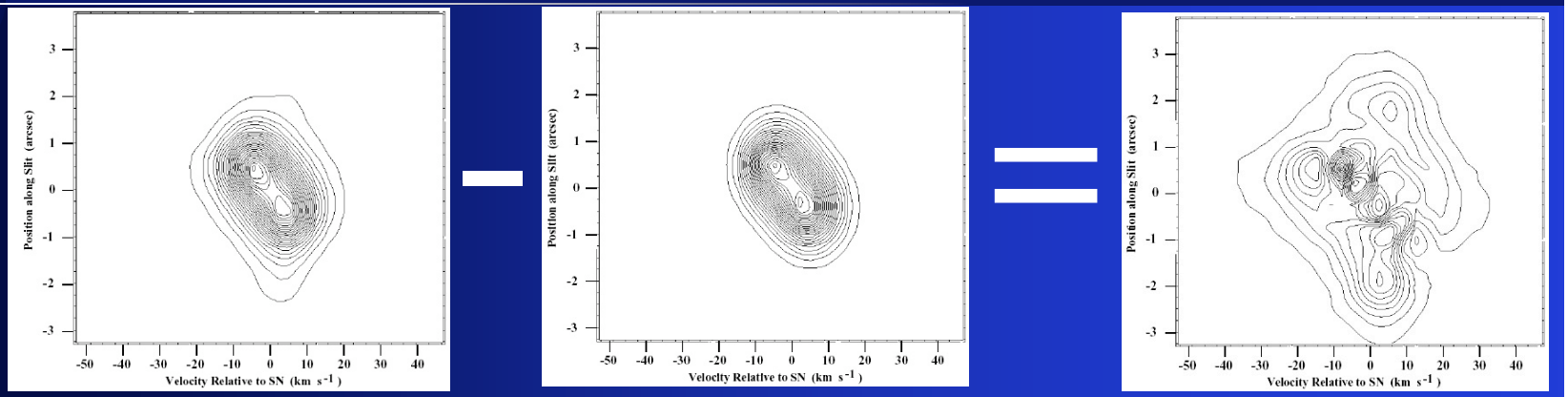
CTIO 4m/Echelle 1989-2004



~3400-9800A, 8 km/s resolution

3-Ring Velocities & Kinematic Ages

CT4m/Echelle [N II] Locus - ring expansion model

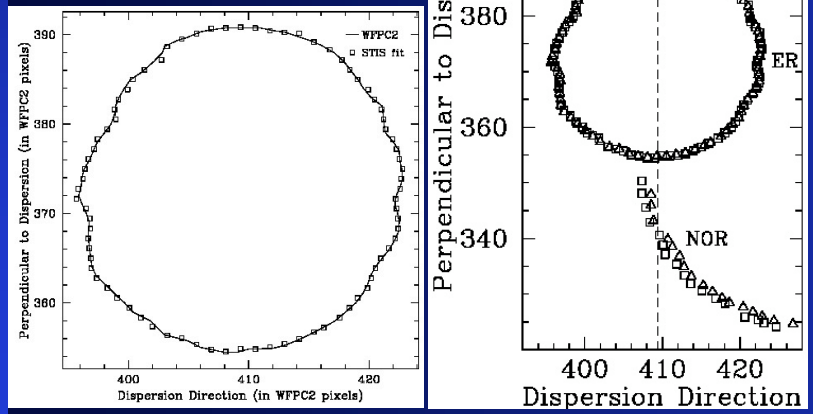


ER= Equatorial Ring

SOR= Southern Outer Ring

NOR= Northern Outer Ring

HST/STIS Dispersed [N II] Image Shifts versus WFPC2 locus



Results:

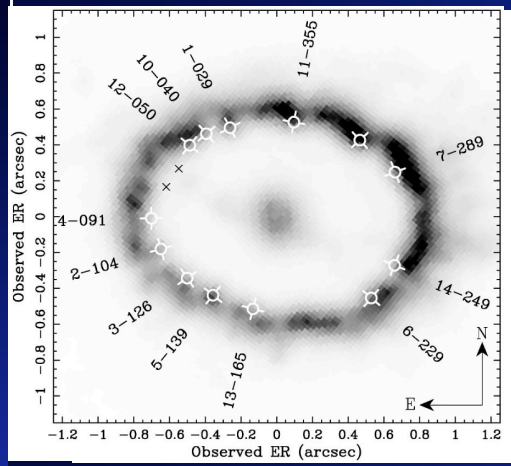
ER expanding at 10.5 ± 0.3 km/s
(Crotts, Heathcote 2000, ApJ; c.f. 10.3 km/s, Crotts & Heathcote '91, Cumming '94; 11 km/s, Panagia et al. '96; 8 km/s, Meaburn et al. '95)

NOR expanding at 26.1 ± 2 km/s
SOR expanding at 26.3 km/s (or 25.5 km/s depending on SOR inclination)

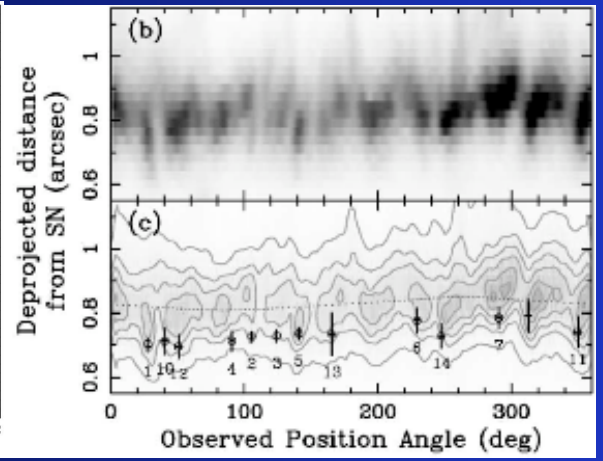
Kinematic Ages: ER 19500 y
NOR 21700 y
SOR 19000 y (20800 y)

Hotspot Loci & Motion

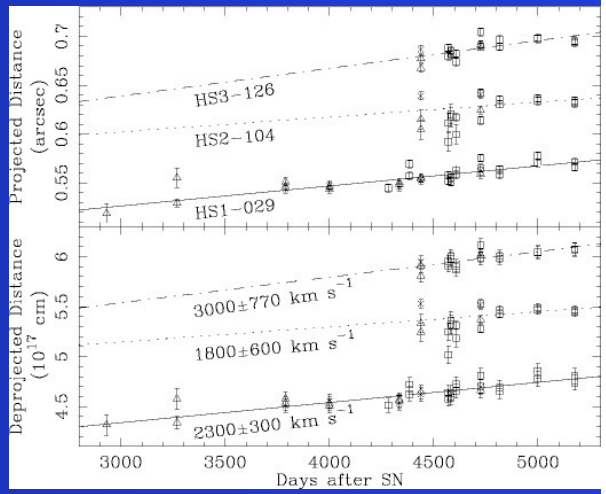
Sugerman, Lawrence, Crotts, Bouchet, Heathcote 2002, ApJ, 572, 209



First 13 hotspot loci, interior to ring



Ring & hot spots deprojected



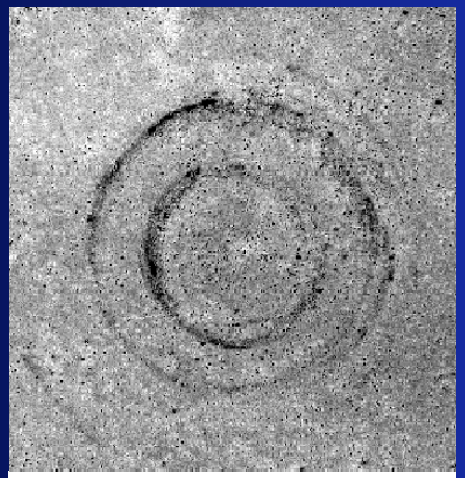
Hotspot proper motion ~2000km/s

Simple prediction: first (innermost) hot spots show largest degree of Rayleigh-Taylor finger instability, so will tend to decrease in cross-section and move more relative to later spots, which are more pyramidal or bulged rather than finger-like in shape along radial projection.

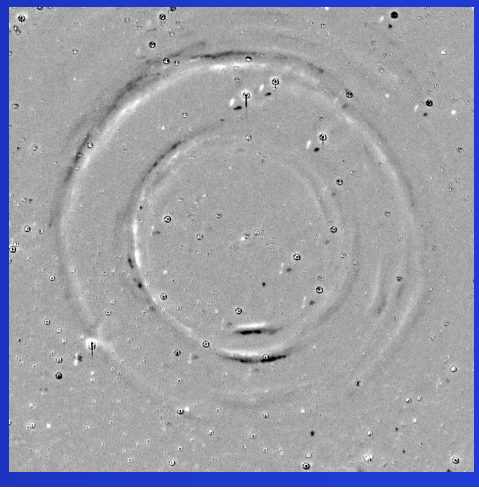
Ejecta & wind outflow away from SN

Some Image-Subtracted Echoes

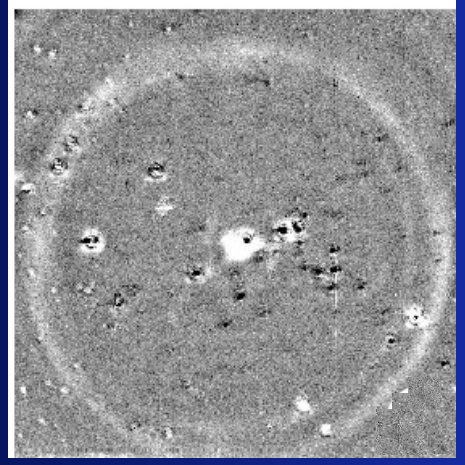
LCO 1-m
Jan. 1991
rough
"no-echo"
subtraction



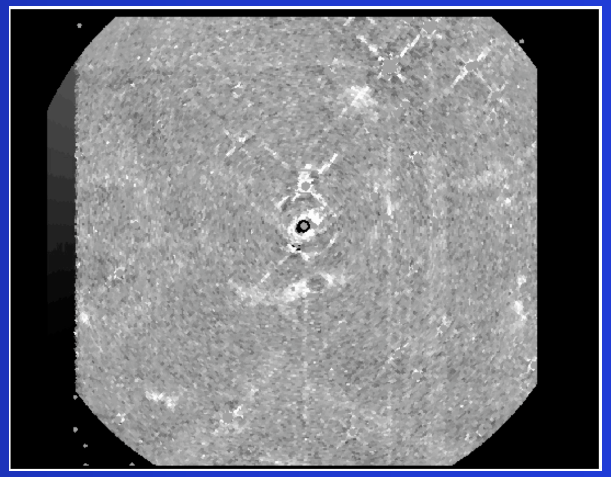
LCO 1-m
Mar. 1995 minus
Mar. 1996
"exact" 2-epoch
subtraction



LCO 1-m
Dec. 1989
exact
"no-echo"
subtraction

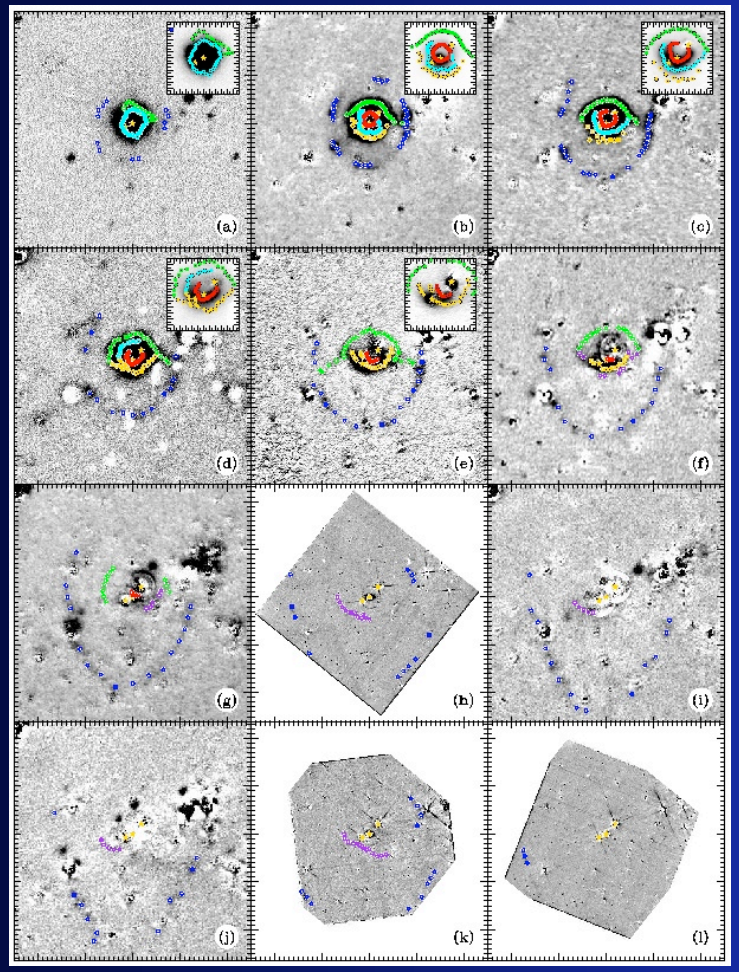


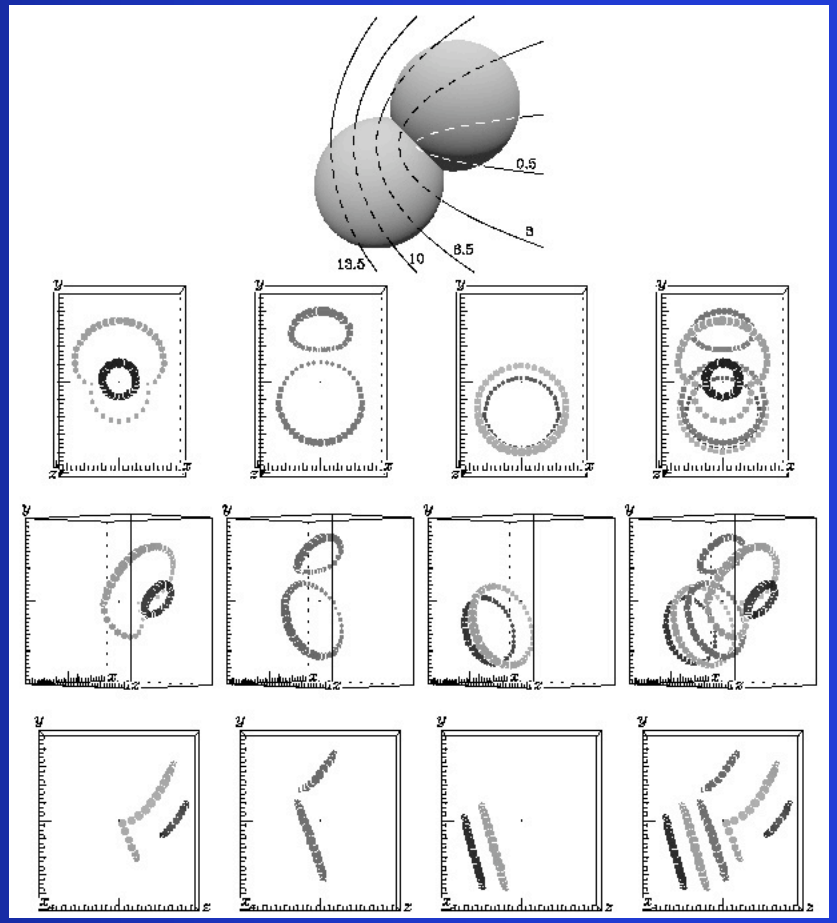
WFPC2
Oct. 1994
Exact
"no-echo"
subtraction



Echo complexes at SN foreground distances: 1 kpc, 400-550 pc, (300 pc), 110-130 pc, < 5pc

Circumstellar Echo Image Sample





Toy model of echo from double-lobed structure

Sample from Crotts, Kunkel & Heathcote 1995; Sugerman, Crotts, Kunkel, Heathcote & Lawrence 2005

3-D Circumstellar Symmetric Model

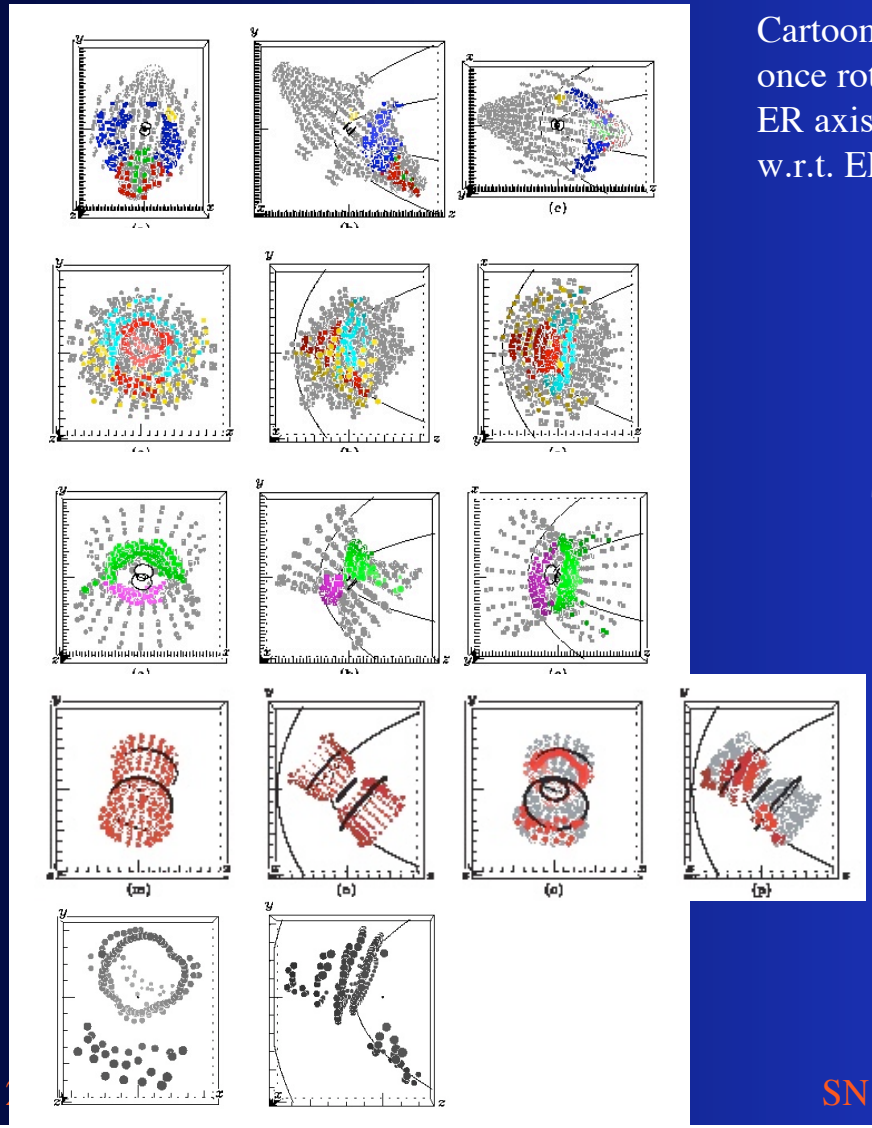
CD = contact discontinuity

CS = diffuse circumstellar echo

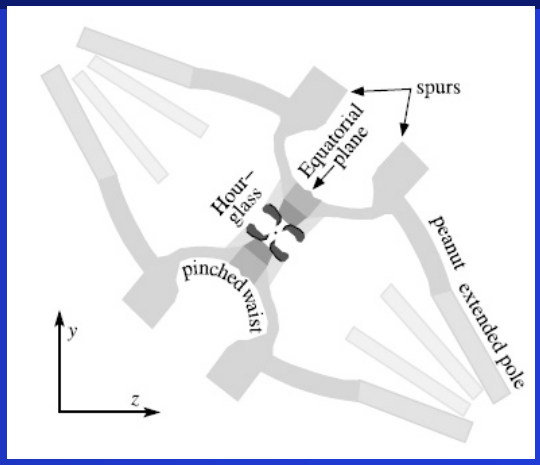
NH = Napoleon's Hat and Bib

HG = hour glass nebulosity

observed HG points w/o symmetric extrapolation



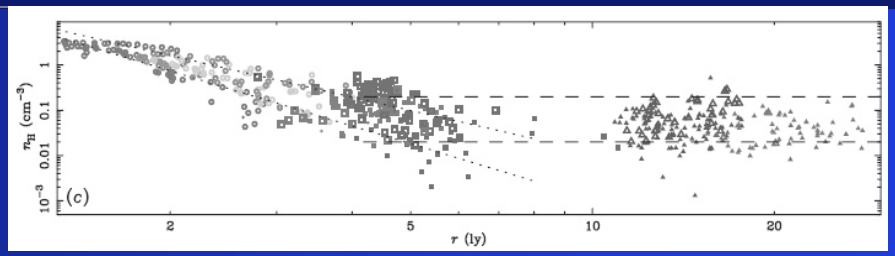
Cartoon of structure once rotated around ER axis and flipped w.r.t. ER plane



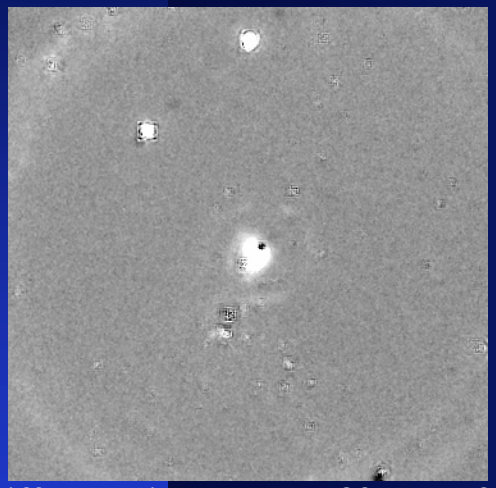
The "Napoleon's Hat" echo pairs with "Napoleon's Bib" found by us in HST imaging, recovered in ground-based images. We (somewhat arbitrarily) dissect the 3-D echo structure into four nested foliations. A diffuse echo (with 3-D connected structure) permeates a large part of the volume. Velocities in these regions (~15-20 km/s) give kinematic ages $\gtrsim$350000 y (from CTIO 4m longslit Echelle grid).

Polarimetry of Diffuse Circumstellar Echo

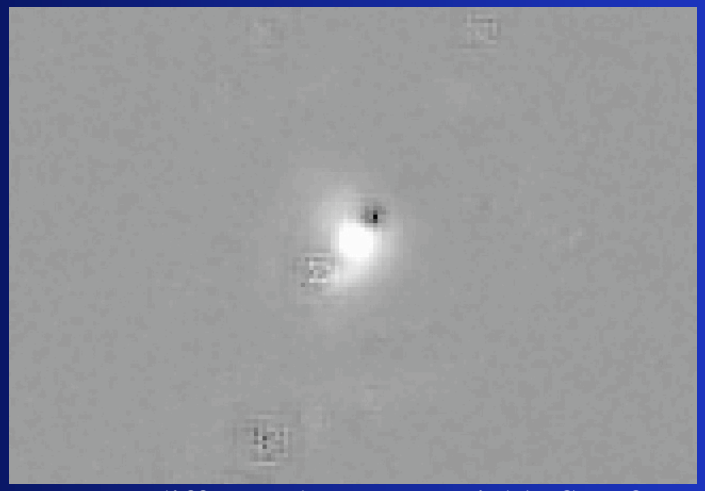
We completed three epochs of imaging linear polarimetry in 1989 hoping that if diffuse echo was well-behaved we might find geometric distance to LMC assuming radius r of max P of 90^{o} scattering occurs at angle θ = ct/D e.g., Sparks 1994.



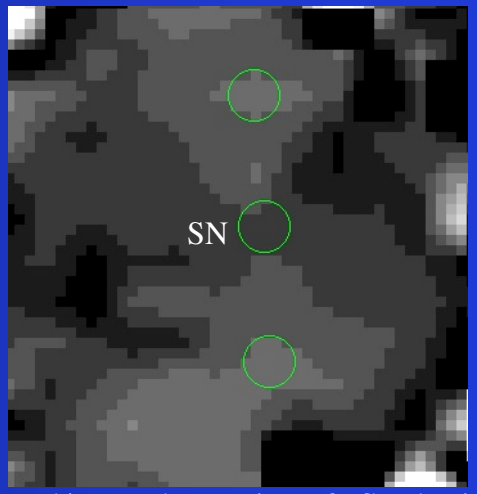
Radial plot of inferred gas density (assuming constant gas/dust)



Difference image: Dec. 89 - Jan. 96



Zoom, diffuse echo: note variable Star 2



Pol/un-Pol: maxima & SN loci

We can do this measurements (each summing 4-8 exposures) on 3 polarizations ∗ 4 bands ∗ 3 epochs:
Typical maximum P = 18%; r = 13.1 ± 0.1 pixel = 3”.01 ± 0”.03, t = 2.6 y after maximum => D = 54 kpc
This is a PRELIMINARY (brute force) result; we are redoing this measurement fitting all pixel ratios using a maximum likelihood estimator and evaluating more carefully systematic effects.